

Study with reflected ultrasound of patients with mitral valve repair

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As part of a follow-up investigation in mitral annuloplasty by reflected ultrasound, 39 studies have been carried out in 15 patients who underwent mitral valve reconstructive operations. The rate of diastolic toward closure movement from point E (EF speed) and total amplitude did not correlate with the final valve orifice dimension obtained at operation. Mitral stenosis and incompetence were shown within the first 6 months after repair. Such a noninvasive technique is therefore regarded as an additional method of study of the structural and functional state of the mitral valve after annuloplasty and the subsequent changes in time. The contribution of mitral ring movement to the familiar mitral echogram pattern is discussed passim.

The value of studying the mitral valve by reflected ultrasound technique is now well established (Edler *et al.*, 1961; Edler, 1967; Effert *et al.*, 1964; Joyner, Reid, and Bond, 1963; Segal, Likoff, and Kingsley, 1966; Wharton and Lopez Bescos, 1970; Winters *et al.*, 1967). In mitral valve disease the results of mitral echocardiography have been shown to correlate well with various pathological contributing mechanisms and, in patients with significant mitral stenosis, with the size of valve orifice also (Dillon *et al.*, 1971; Effert, 1967; Gustafson, 1966, 1967; Joyner *et al.*, 1963; Segal *et al.*, 1966; Segal, Likoff, and Kingsley, 1967; Wharton and Lopez Bescos, 1970; Winters *et al.*, 1967).

Reconstructive valve surgery in mitral incompetence with or without stenosis continues to be preferred under defined conditions, in view of the complications and uncertainty of long-term prognosis in mitral valve replacement (Ellis, 1967; Kerth *et al.*, 1971; Manhas *et al.*, 1971; Morrow *et al.*, 1967; Reed, 1968; Ross, 1972; Selzer *et al.*, 1972). Clinical and haemodynamic results of mitral valve repair have been reported (Aldridge, Lipton, and Bigelow, 1966; Anderson *et al.*, 1962; Bigelow *et al.*, 1961; Ellis, 1967; Logan, Turner, and Kitchen, 1967; Manhas *et al.*, 1971; Pakrashi *et al.*, 1972; Penther, Bourdarias, and Lenègre, 1970; Reed, Tice, and Clauss, 1965; Reed, 1968; Steinmetz *et al.*, 1962; Wooler *et al.*, 1962), but published studies with reflected ultrasound are very scanty (Segal *et al.*, 1967; Ultan, Segal, and Likoff, 1967; Winters *et al.*, 1967).

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This report is based on a study of an initial series of 15 patients with mitral annuloplasty, in an attempt to investigate: (1) ultrasonic criteria related to the quality of postoperative results, the evolution of residual pathology, and the use of these criteria in the follow-up of such patients; and (2) the role played by ring movement in the production of the mitral echogram which was recently emphasized (Chakorn *et al.*, 1972; Siggers, Srivongse, and Deuchar, 1971; Zaky, Nassar, and Feigenbaum, 1968).

Subjects and method

Thirty-nine studies with reflected ultrasound were performed in 15 consecutive patients; 12 were studied immediately and at varying intervals for a period of up to 6 months after operation. In the remaining 3 patients studies were performed at 3 months only in one case, at 6 months only in another, and at both 3 and 6 months in the third (Table 1).

The aetiology of mitral valve disease was rheumatic in 13 patients; 1 of whom had suffered additional infective endocarditis. Of the remaining 2 patients, 1 was found to have cardiomyopathy and the other had a congenital mitral valve defect. Their ages ranged between 10 and 66 years (mean 45 years) (Table 1). Nine of these patients had preoperative pure or predominant mitral incompetence and 6 had mixed mitral valve disease. Other valve lesions were encountered in 5 patients: 3 had tricuspid and 2 aortic incompetence.

The final decision to repair the mitral valve was taken after inspecting it during operation. None of the patients had fluoroscopic evidence of significant mitral calcification.

TABLE I Details of 15 patients with mitral valve reconstructive surgery

Case No.	Age (yr), sex	Surgical procedure in addition to annuloplasty	Mitral valve leaflets		DMVO (mm)	Reflected ultrasound criteria after annuloplasty			
			Aortic	Mural		Time of study	Total amplitude (mm)	EF speed (mm/sec)	Heart rhythm
Nine cases of preoperative pure or predominant mitral incompetence									
1*	49 F	Plication of posterior leaflet	Thin; pliable	Thickened free edge	42	Initial	37	47	SR
						3 mth	40	117	AF
						6 mth	40	113	AF
2	58 M	Plication of posterior leaflet	Thin; pliable	Thin; overshooting	38	Initial	34	91	AF
						3 mth	34	91	AF
						6 mth	29	70	AF
3	60 F		Slightly thickened; pliable; overshooting	Slightly thickened	34	Initial	18	44	AF
						3 mth	15	38	AF
						6 mth	17	41	AF
4	60 F	Commissural incision; papillary muscle incision	Thickened free edge; pliable; overshooting	Thickened; fibrotic	34	Initial	18	62	AF
		Chordal separation				3 mth	19	49	AF
						6 mth	18	32	AF
5	45 F		Just thickened; pliable	Slightly thickened	32	Initial	17	50	AF
						3 mth	19	57	AF
6†	57 M		Thin; pliable	Thin; stretched	35	Initial	14	36	AF
7	17 F		Thin; pliable	Thin; pliable	34	Initial	24	84	AF
8	59 M	Commissural incision; papillary muscle incision	Thickened; pliable	Thickened; fibrotic	34	Initial	20	46	AF
9	66 F	Papillary muscle incision	Thin; pliable	Thickened; stretched	30	3 mth	17	43	AF
Six cases of preoperative mixed mitral valve disease									
10	56 F	Commissural incision; papillary muscle incision	Thickened free edge; pliable	Thickened; fibrotic	35	Initial	25	47	AF
						3 mth	20	36	AF
11	43 F	Commissural incision; papillary muscle incision; chordal separation	Slightly thickened; pliable	Slightly thickened; pliable	34	Initial	20	49	AF
12	44 M	Commissural incision; removal of calcification from posterior commissure	Thickened posterior part; pliable anterior part	Thickened posterior part; pliable anterior part	40	Initial	23	68	SR
13‡	10 F	Commissural incision; papillary muscle incision	Thickened free edge; pliable	Thickened free edge; pliable	24	Initial	21	51	SR
14	32 F	Commissural incision; removal of calcification from anterior commissure	Thickened free edge; pliable	Thickened free edge; pliable	34	3 mth	21	54	AFI
						6 mth	26	41	AFI
15	23 F	Commissural incision; removal of calcification from posterior commissure	Thickened; pliable	Thickened; calcified	30	6 mth	12	32	SR

SR, sinus rhythm; AF, atrial fibrillation; AFI, atrial flutter; DMVO, dimensions of mitral valve orifice achieved by annuloplasty.

* Patient developed significant mitral incompetence three months postoperatively.

† Patient with cardiomyopathy.

‡ Patient with congenital mitral valve defect.

Surgical procedure

All patients had open mitral annuloplasty (Wooler *et al.*, 1962). A pliable anterior leaflet and absence of extensive calcifications were necessary prerequisites. Commissural adhesions, mild chordal agglutination, ruptured chordae tendineae of the posterior leaflet, slight thickening of the free edge, and moderately diseased posterior leaflet were accepted. The details of valve pathology and surgical technique are shown in Table 1.

In all the patients an estimate of the dimensions of mitral valve orifice was made using Tubb's dilators. The two blades of the dilators were opened in a plane at right angles to the intercommissural line. The orifices (24–42 mm) achieved after repair were judged to be adequate by the surgeon. At the conclusion of the operation, none of the patients was considered to have significant mitral regurgitation. Two patients required aortic and 1 tricuspid valve replacement; 2 other patients had tricuspid valve repair.

Postoperative assessment

All 15 patients survived the operation, 13 of whom had lost the mitral systolic murmur, while the remaining 2 patients had a very soft, localized apical systolic murmur of grade 1/6. Three months later, 1 of these 2 developed a grade 3/6 pansystolic murmur which radiated to the axilla and back; her clinical course confirmed the recurrence of significant mitral incompetence. In 11 patients a very short mid-diastolic murmur could be heard.

Study with reflected ultrasound

Ultrasound cardiography was performed using an Ekoline 20 ultrasonoscope equipped with a 2.25 megacycle/sec transducer probe (13/16 in. face diameter) which transmits and receives pulsed echoes at a frequency of 1000 pulses/second. Ultrasound recordings were obtained by direct polaroid photography from the oscilloscope of the

instrument. All studies were performed by one investigator, using whenever possible the same site and probe inclination for each patient (Gustafson, 1966). The third and fourth interspaces were used 1 to 4 cm from the midsternal line with the patient in the supine position. In 10 patients, 13 simultaneous recordings of maximal ring and leaflet excursions were obtained. This was possible from a site nearer to the apical impulse (Table 2).

Initial studies were performed on the 10th postoperative day. No failure was encountered in obtaining the echo from the anterior leaflet of the mitral valve. The total amplitude (CE) was obtained by measuring the maximal vertical excursion inscribed, and the rate of diastolic movement towards closure from point E (EF slope) was measured as the average of at least 4 slopes (Edler, 1967).

When the echo of the mitral ring was recorded, the total excursion of the ring was obtained by measuring its maximal vertical motion. The rate of early diastolic receding movement (HI slope) was measured as the average of at least 4 slopes (Zaky, Grabhorn, and Feigenbaum, 1967). The portions of the leaflets beyond the annuloplasty sutures made it easier to obtain ring echoes. Such portions were assumed to follow ring motion, in view of the fixity and approximation imparted by the sutures.

Results

Errors in measurements of total amplitude and EF slope, by the same person at different times, were assessed. The differences in results were statistically insignificant. (Total amplitude $P > 0.05$ and EF speed $P > 0.1$.) The standard errors of the single estimate were 2.99 mm and 5.68 mm/sec, respectively.

TABLE 2 Results of reflected ultrasound studies in 10 patients at varying intervals after mitral annuloplasty

Case No.	Time of study after annuloplasty	DMVO (mm)	Ring receding rate (mm/sec)	Maximal ring amplitude (mm)	EF speed (mm/sec)	Total valve amplitude (mm)
1	Initial		40	8	50	37
	6 mth	42	38	11	105	40
2	Initial	38	79	14	86	34
3	Initial		23	7	55	17
	2 mth	32	30	6	55	19
4	Initial	34	39	7	45	20
5	Initial	34	34	5	40	20
6	Initial	40	55	7	63	23
7	Initial	34	53	8	92	24
8	Initial	24	48	9	59	21
9	3 mth	30	31	6	42	17
10	2 mth		44	10	57	21
	6 mth	34	35	9	51	26

There was no ultrasonic evidence of left atrial thrombi in any of these patients.

Initial studies

Twelve patients were investigated in the initial postoperative period (Table 1). None of them had had evidence of left ventricular failure or severe low cardiac output state and were clinically well. Nine patients were in atrial fibrillation and 3 in sinus rhythm. Their ventricular rate ranged from 74 to 115 beats/minute (mean 96 beats/minute). The amplitude of valve excursions and EF speeds ranged from 14 to 37 mm and from 36 to 91 mm/sec, respectively. The lowest values of these parameters were obtained from the patient with cardiomyopathy. The diameter of the mitral valve orifice did not show significant statistical correlation with either amplitude of valve excursion ($r=0.5551$ $P>0.05$) or EF speed ($r=0.2085$ $P>0.05$) (Fig. 1). In 6 patients who had operations on subvalvular structures, and commissural incisions, valve excursions and EF speeds ranged from 18 to 25 mm and from 46 to 68 mm/sec, respectively.

The rapid closing movement of the anterior

leaflet during early diastole (Edler, 1967), was discernible in only 2 patients.

Follow-up studies

Three months after annuloplasty, studies were repeated in 6 patients, all of whom were in atrial fibrillation. No statistically significant changes were noted in the ventricular rates ($P>0.4$), valve excursions ($P>0.9$), and EF speed ($P>0.1$) in between these two studies. One patient developed significant mitral incompetence (Table 1); her valve excursions and EF speed remained within normal limits.

Six months after repair, 5 patients, including the one with mitral incompetence, had further studies. One of them with thickened mitral leaflets at operation developed ultrasonic criteria of mitral stenosis. A further patient who was found to have thickened cusps at operation was studied once only 6 months after operation. Her echocardiogram was consistent with mitral stenosis.

Mitral ring studies (Table 2)

In 8 patients studied during the initial postoperative period, the diameter of the mitral valve orifice

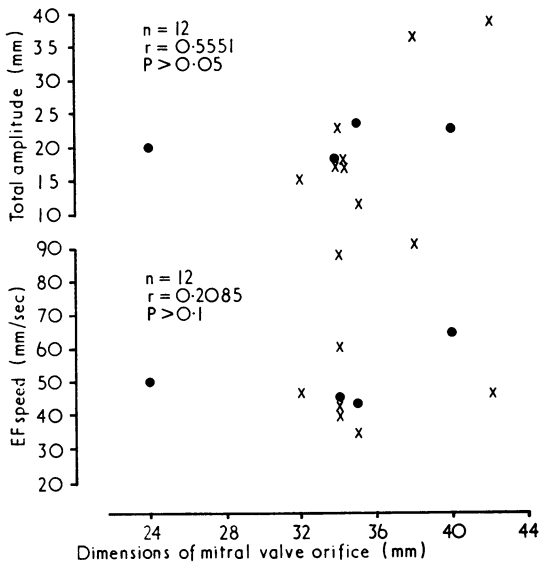


FIG. 1 Patients studied in the initial postoperative period after mitral valve repair. Correlation of the dimensions of mitral valve orifice with EF speed (bottom figure) and with total valve amplitude (top figure). \times , patients with preoperative pure or predominant mitral incompetence. \bullet , patients with preoperative mixed mitral valve disease. n , number of studies; r , coefficient of correlation; P , statistical probability.

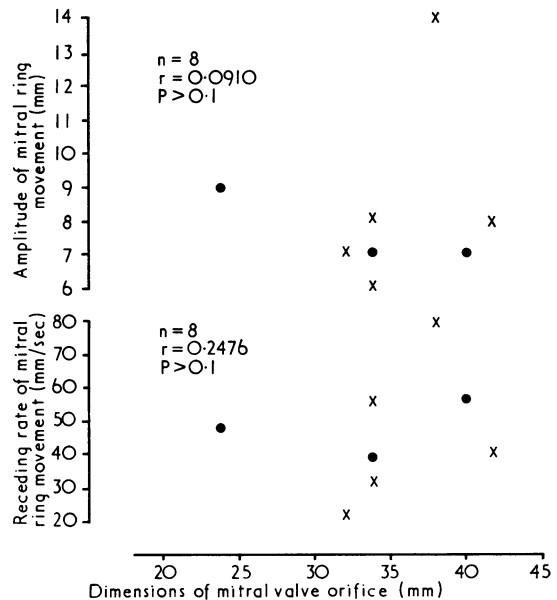


FIG. 2 Patients studied in the initial postoperative period after mitral valve repair. Correlation of the dimensions of mitral valve orifice with the receding rate of mitral ring movement in diastole (bottom figure) and with amplitude of mitral ring movement (top figure).

revealed (Fig. 2) insignificant correlation with both ring amplitude ($r=0.0910$, $P>0.1$), and receding rate ($r=0.2476$, $P>0.1$).

In 10 patients, 13 studies were obtained initially and at varying intervals of up to 6 months after operation. Excluding one study performed after the development of mitral incompetence, the amplitude of ring motion revealed (Fig. 3) significant correlation with total valve amplitude ($r=0.6113$, $P<0.05$). The speed of receding movement during diastole (Fig. 4) correlated well with EF slopes ($r=0.7337$, $P<0.001$).

The amplitude of ring excursion was below the normal levels reported by Zaky *et al.* (1967). The diastolic receding movement was slower than the corresponding EF speed. The biggest difference between the two was obtained in one patient after the onset of postoperative mitral incompetence.

Discussion

Echograms obtained from patients with normal mitral valves reveal a total amplitude of 19–40 mm and EF speed 70–210 mm/sec (Edler, 1967; Effert *et al.*, 1964; Gustafson, 1966; Joyner, Reid, and Bond, 1963; Segal *et al.*, 1966; Wharton and Lopez Bescos, 1970; Winters *et al.*, 1967). Significant mitral stenosis can be inferred from an EF slope of less than 35 mm/sec (Effert *et al.*, 1964; Effert, 1967; Gramiak and Shah, 1971; Joyner and Reid, 1963; Winters *et al.*, 1967). Total amplitude below 10 to 15 mm was shown to indicate significant diminution of anterior leaflet mobility, as seen on angiocardiology or at operation (Edler, 1967; Gustafson, 1966, 1967; Wharton and Lopez Bescos, 1970). In the patient with cardiomyopathy described in this report, both ultrasonic criteria were significantly below normal levels following annuloplasty. Similar

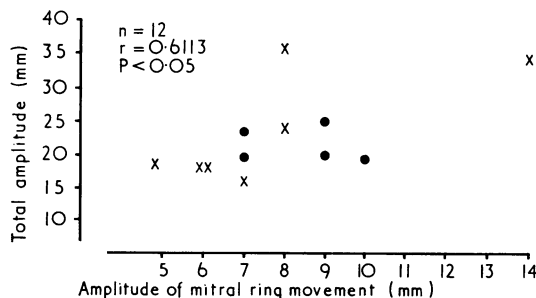


FIG. 3 Patients studied, immediately and at varying intervals up to 6 months after mitral valve repair. Correlation between amplitudes of mitral ring and valve excursions.

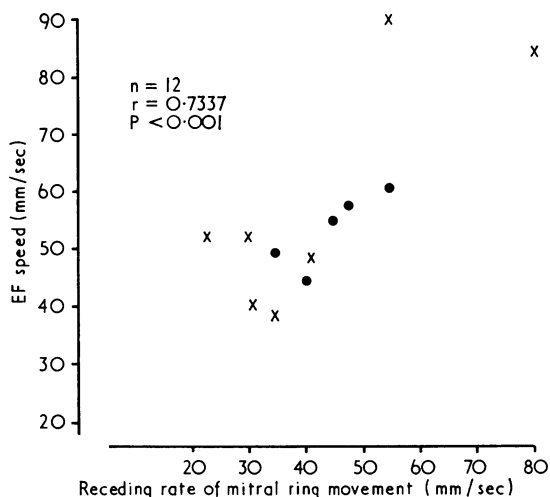


FIG. 4 Patients studied, immediately and at varying intervals up to 6 months after mitral valve repair. Correlation between the speed of mitral ring movement during diastole and valve closure movement during diastole (EF).

results were described in patients with hypertrophic cardiomyopathy and primary myocardial disease (Feigenbaum, 1972; Moreyra *et al.*, 1969; Pridie and Oakley, 1970; Shah *et al.*, 1968; Shah, Gramiak, and Kramer, 1969).

None of the remaining 11 patients, who were studied during the initial postoperative period, had ultrasonic criteria suggesting significant mitral stenosis or impaired mobility of the anterior leaflet. Normal EF speed was encountered however, in only 2 patients. Similar observations were made in patients undergoing mitral valvotomy. The lack of regaining normal EF speed was attributed to advanced cuspal disease and calcification (Edler, 1967; Effert *et al.*, 1964; Effert, 1967; Joyner *et al.*, 1963; Silver, Rodriguez-Torres, and Newfeld, 1969). In this series, such advanced pathology of the cusps was absent. Good correlation has been reported between surgical or calculated mitral valve area and EF speed (Edler, 1967; Effert, 1967; Joyner *et al.*, 1963; Segal *et al.*, 1966; Wharton and Lopez Bescos, 1970; Winters *et al.*, 1967). After valve repair, the slower than normal EF speed obtained in the majority of our patients did not seem to be totally attributable to the valve size achieved by annuloplasty, in view of the lack of correlation seen between the EF speed and the diameter of the mitral valve orifice as measured at operation.

Other factors known to influence the EF speed, such as aortic stenosis or incompetence (Moreyra

et al., 1969; Pridie, Benham, and Oakley, 1971; Shah *et al.*, 1969) and atrial thrombus (Edler, 1961a; Effert *et al.*, 1964; Segal *et al.*, 1966), were absent in our series.

Disease of the leaflets and chordae tendineae has been shown to influence EF speed (Gustafson, 1967; Segal *et al.*, 1966; Wharton and Lopez Bescos, 1970; Winters, Hafer, and Soloff, 1969). In our patients, anterior leaflet pliability as observed at operation and its total excursion as seen during reflected ultrasound study, indicated a minor influence of such factors.

The EF slope, as inscribed by anterior leaflet movement (Edler, 1961b; Effert *et al.*, 1964; Feigenbaum *et al.*, 1970; Gramiak, Shah, and Kramer, 1969) has been explained on the basis of either subvalvular vortex formation (Bellhouse, 1972; Reid, 1969; Segal *et al.*, 1967), chordal traction (Davila and Palmer, 1962; Pridie *et al.*, 1971; Rushmer, 1970), or mitral ring movement (Chakorn *et al.*, 1972; Feigenbaum, 1972; Siggers *et al.*, 1971; Zaky *et al.*, 1968). The latter mechanism is in keeping with the correlation observed here between ring receding rate and EF speed. Ring receding movement during diastole has been shown to be more gradual and protracted in mitral stenosis than in normal valves, probably indicating a decreased rate of ventricular filling (Zaky *et al.*, 1968). In this series, the absence of significant correlation between EF speed or ring receding rate and diameter of the mitral valve orifice might have been caused by other factors which can influence the rate of left ventricular filling such as myocardial disease or hypertrophy (Moreyra *et al.*, 1969; Pridie and Oakley, 1970; Shah *et al.*, 1968, 1969), left ventricular cavity volume (Bellhouse, 1972), and a combination of these factors (Pridie, Benham, and Wild, 1972). Such factors might also explain the type of correlations observed in this series between the diameter of mitral valve orifice and the amplitude of valve or ring excursion. During ventricular systole the ring and leaflet excursions contribute to the total amplitude of mitral echogram (Chakorn *et al.*, 1972; Effert, 1967; Winters *et al.*, 1967; Zaky *et al.*, 1968). The ring amplitude itself was shown to be affected by changes in ventricular stroke volumes (Chakorn *et al.*, 1972). In this series the amplitude of valve movement correlated well with ring excursion but not with the diameter of the mitral valve orifice. It is possible, therefore, that left ventricular stroke volume was influenced by factors other than the mitral valve orifice (Feigenbaum, Linback, and Nasser, 1968). Furthermore, it is inherent in this method that such assessment of dimensions might be influenced by the degree of subclinical leaflet disease.

Reconstructive operations of the mitral valve, for

incompetence and mixed disease, maintain a definite place in suitable cases (Dubost, 1971; Ellis, 1967; Kerth *et al.*, 1971; Kloth *et al.*, 1968; Logan *et al.*, 1967; Manhas *et al.*, 1971; Penther *et al.*, 1970; Reed, 1968).

Long-term results have indicated clinical improvement in the majority of patients undergoing annuloplasty. Haemodynamic studies however have revealed the development of mitral stenosis and incompetence. Mitral stenosis developed not only in patients with chordae tendineae and leaflet disease, but also in those with pure mitral incompetence and good valvular tissue (Pakrashi *et al.*, 1972). The stenosis has been attributed to a continuing subclinical inflammatory process (Aldridge *et al.*, 1966). Its relation to smaller mitral valve area achieved at operation was emphasized by Anderson *et al.* (1962), Bjork and Malers (1964), Penther *et al.* (1970), and Reed *et al.* (1965). In 2 of our patients, ultrasonic criteria indicating mitral stenosis were obtained 6 months after annuloplasty. The first was known to have predominant mitral incompetence before operation, and at operation the mural cusp was found thickened and the chordae diseased. Postoperative mitral echograms revealed progressive diminution of EF speed, with no changes in valve excursion. The second patient, known to have mixed mitral valve disease before operation and thickened mitral leaflets at operation, was studied once only 6 months after operation. The total amplitude and EF speed of the mitral echogram were significantly below normal limits (Table 1). It cannot be certain whether such subclinical stenosis in the second patient proceeded immediately upon operation or has developed later. Winters *et al.* (1967) reported a patient with mitral incompetence due to a defect at the angle of the medial commissure. The valve leaflets were otherwise normal. After suturing and plicating the defect, the patient developed a murmur of mitral stenosis with an EF speed of 29 mm/sec. Edler (1967), in a follow-up study of 100 patients with closed mitral valvotomy, showed that 'some of them' developed reduction of EF speed on mitral echography during the first months after operation. In our patients, it seems unlikely that subclinical inflammatory process or altered flow characteristics alone (Selzer and Cohn, 1972) could have caused stenosis in such a short time. It remains to be seen whether a small diameter of the mitral valve orifice in association with diseased valve can in fact play an additional significant role to expedite the stenotic process. In a pathological study of mitral restenosis, Dekker, Black, and Lichtenberg (1968) showed that the process of cusp and chordal disease was accelerated in patients after mitral valvotomy.

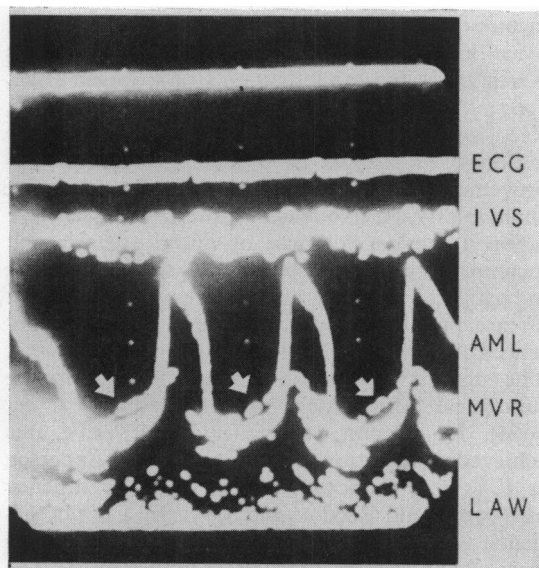


FIG. 5 Simultaneous mitral valve and mitral ring echograms obtained from a site, just medial to the apical impulse of Case 1 (Table 1). ECG, electrocardiogram; IVS, interventricular septum; AML, anterior leaflet of the mitral valve; MVR, mitral valve ring; LAW, posterior wall of the left atrium. During ventricular systole the anterior leaflet is seen posterior to the mitral valve ring (white arrows).

Significant postoperative mitral incompetence represents another complication (Anderson *et al.*, 1962; Ellis, 1967; Kloth *et al.*, 1968; Penther *et al.*, 1970). Postoperative mild regurgitation has been found by Aldridge *et al.* (1966), Penther *et al.* (1970), and Reed *et al.* (1965) to progress into severe mitral incompetence. Only one patient in this series developed recurrence of mitral incompetence though the total amplitude and EF speed were within normal limits. This discrepancy was reported by Effert *et al.* (1964), Joyner *et al.* (1963), Segal *et al.* (1967), Wharton (1969), and Winters *et al.* (1967) who showed that such ultrasonic criteria did not always help in the diagnosis or assessment of the severity of mitral incompetence. The anterior leaflet echo obtained in this patient from a position below mitral valve level, appears to be displaced beyond the echogram of the anterior part of the ring, during ventricular systole (Fig. 5). Such appearance might indicate systolic prolapse of the anterior leaflet into the left atrium.

Intraoperative assessment of mitral valve competence after annuloplasty is not entirely reliable (Ellis, 1967). Few haemodynamic studies have been reported in the early postoperative period (Ellis,

1967; Logan *et al.*, 1967). Follow-up studies with reflected ultrasound in such patients, therefore, offer a noninvasive method for the recognition of early subclinical complications. The time of onset and progress of valve stenosis can be determined, as well as the mechanism of valve incompetence. In addition, it will help to study the relation between the development of these complications and valve pathology observed during annuloplasty, and to define the role played by the mitral ring in valve movement.

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